AAO Based MCPs for Large Area Photo-Detectors

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- **Roadmap for the Development of AAO based MCPs**
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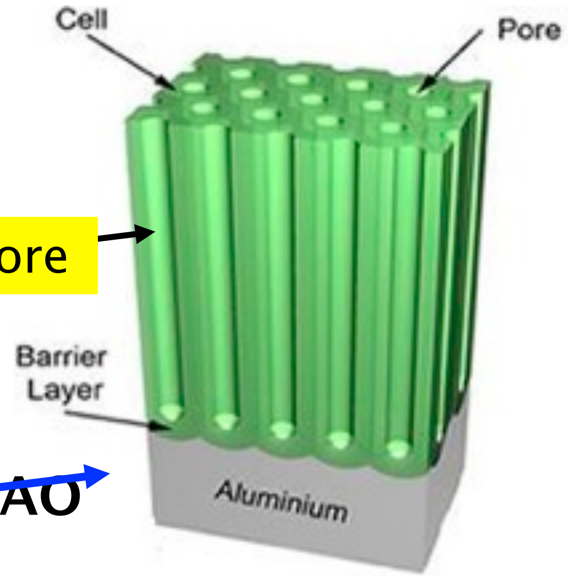
  - **Improved procedure for better micro-machined pores**
  - **Controllable funnel-shaped entrance formation**
  - **Large open area (78%) demonstrated**

What is AAO?

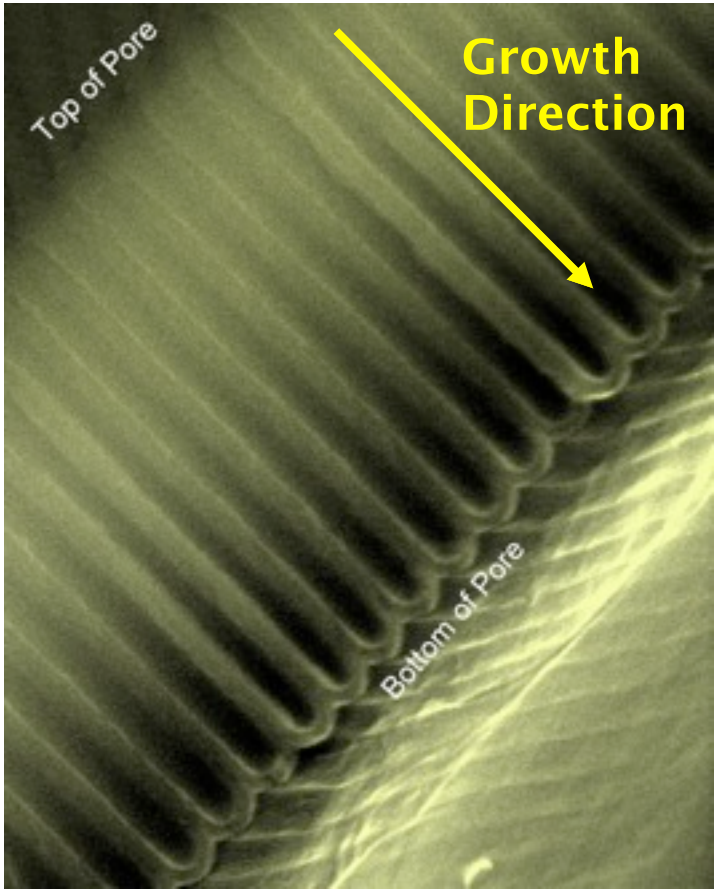
Nanoporous material consists of self-organized hexagonally closed packed nano-scale pores formed by anodizing aluminu

Intrinsic pore



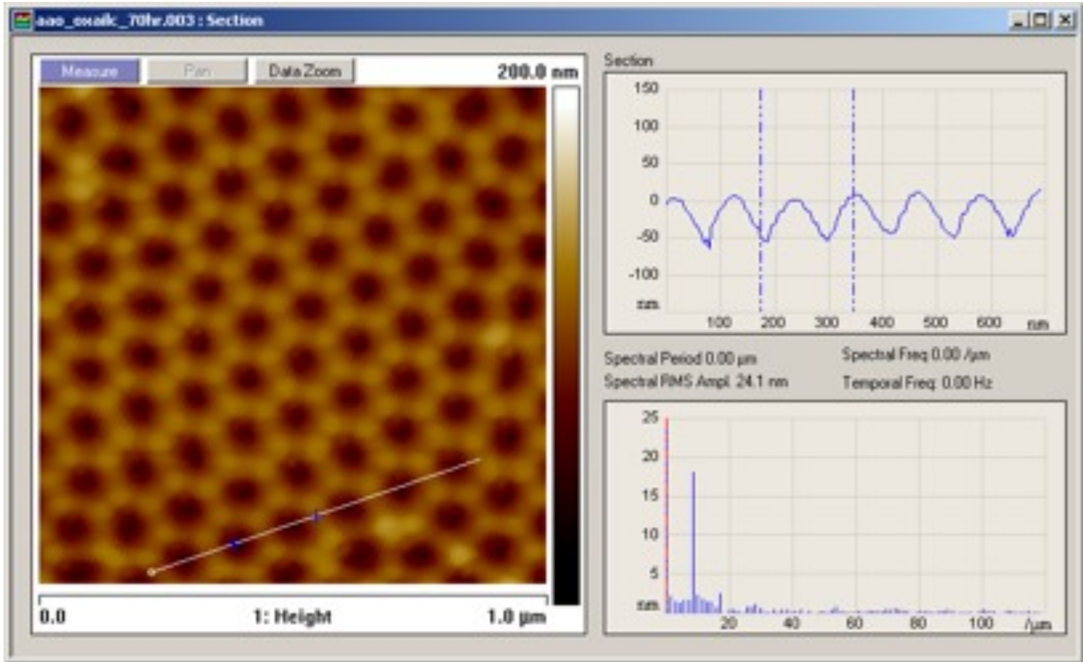
3-D model of AAO

http://www2.chem.umd.edu/Groups/slee/new_site/research.html



http://terpconnect.umd.edu/~pban/Research.htm

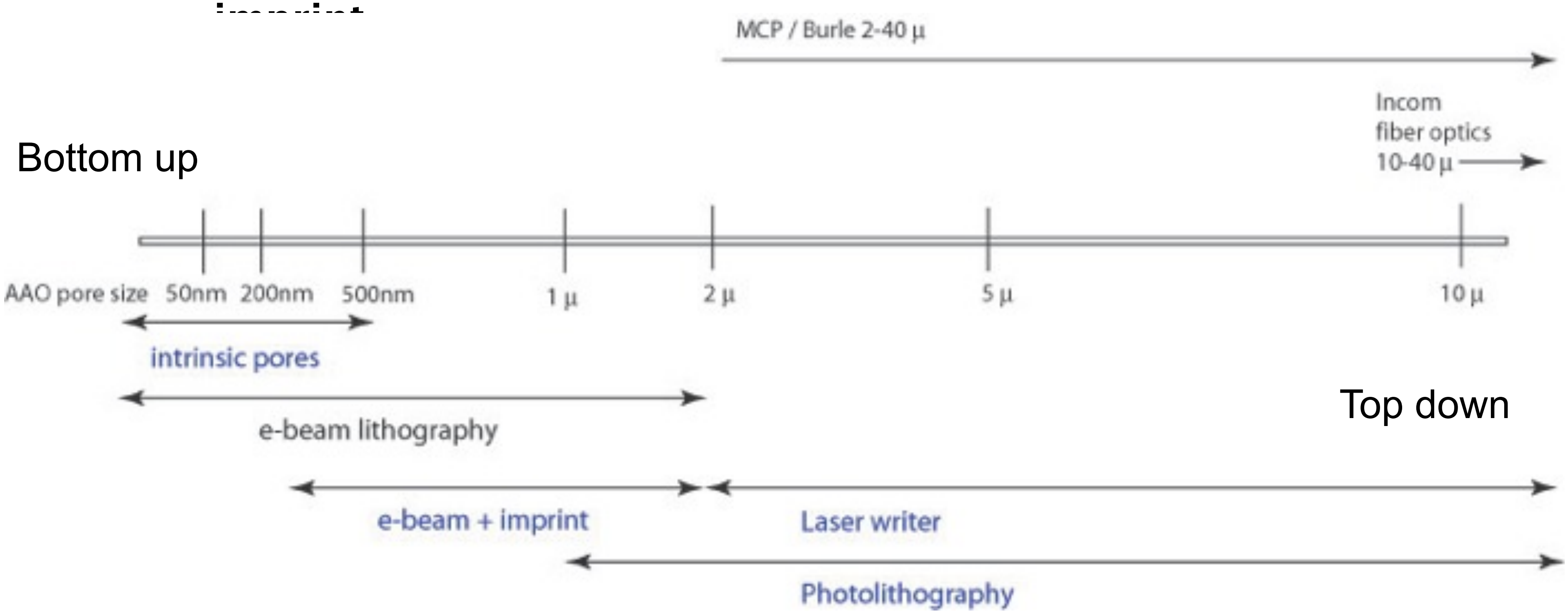
Cross-section of AAO



Atomic Force Microscopy (AFM) image on top of AA

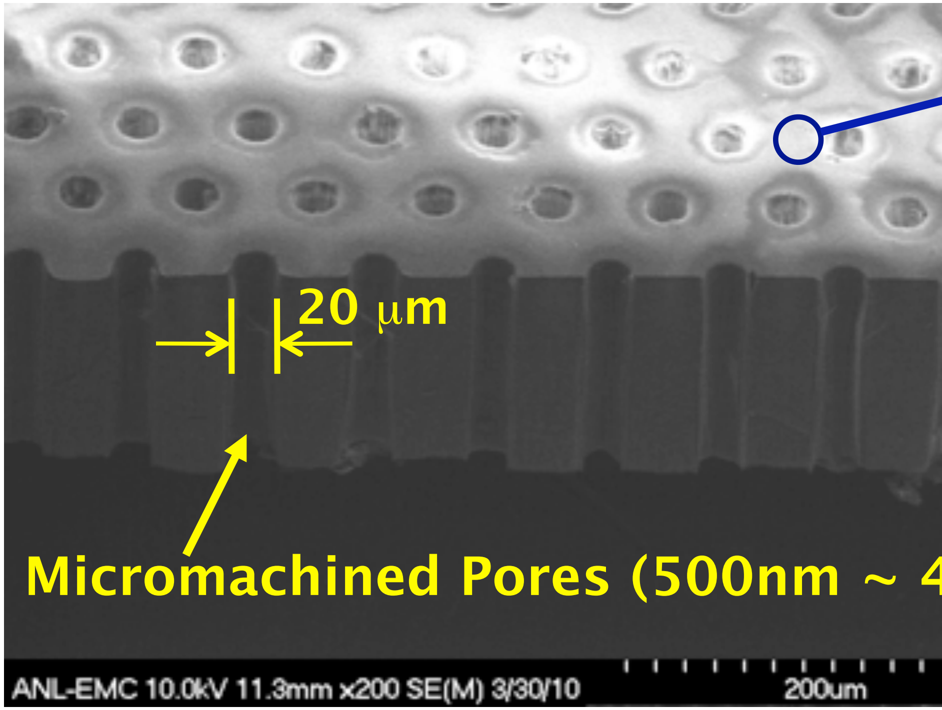
Advantage of AAO based MCPs

1. **Al is inexpensive**
2. **Pore diameter can be varied in a wide range :**
   - **intrinsic pores (20 ~ 500 nm) through anodization**
   - **micro-machined pores (500 nm – 40 μm) through lithography and etching**
   - **32.8 mm – laser writer, 8”X8” Large scale – photomask + imprint**



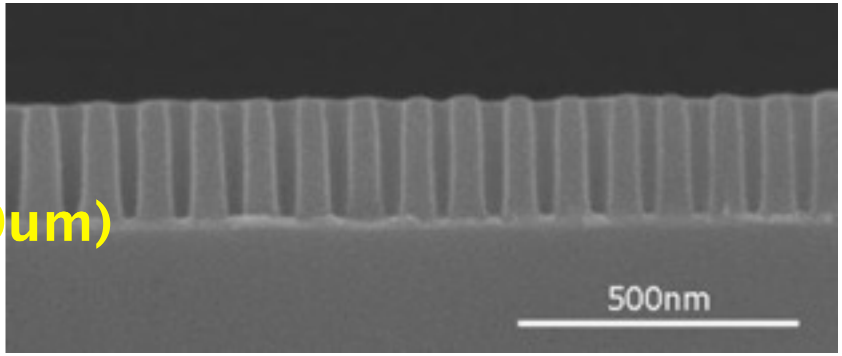
Advantage of AAO based MCP

3. **Intrinsic pores help to create vertical channels through wet**



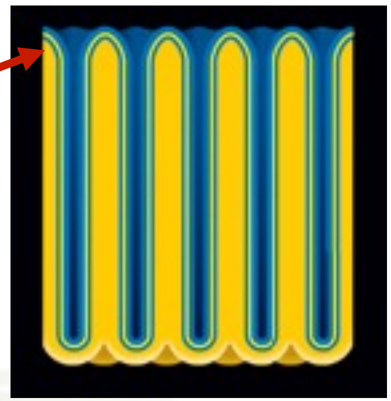
Cross-section of Etched Pores

Intrinsic pores 50 nm



Si etching: not possible to etch deep trench with high aspect ratio

4. **Funnel-shaped entrance can be fabricated**
   - **Intrinsic pores have naturally funnel-shaped entrance**
   - **Funnel-shaped entrance is feasible through etching**



mnemosyne.umd.edu/.../article3773.large.jpg

Roadmap for the development of AAO based MCPs

Develop fabrication process
to create micromachined pores

↓

Optimize L/D for max. gain:
by varying AAO thickness (L) and micromachined pore diameter (D)
Large open area ratio

↓

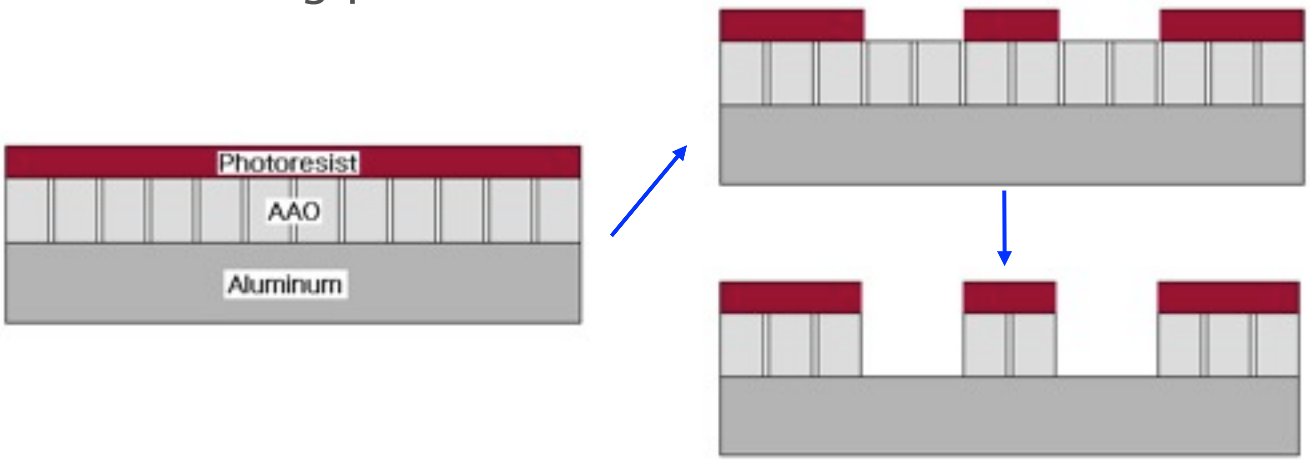
Build funnel-shaped channel entrance
ALD coating to enhance secondary electron emission

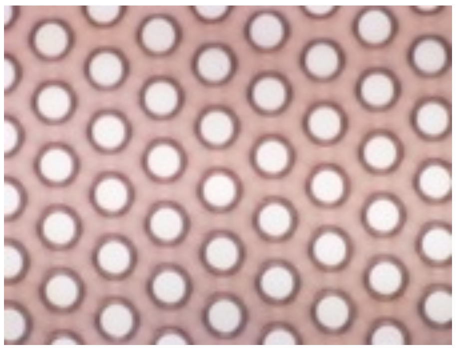
↓

Testing and scale up to 8” X 8” tile

2um, 5um, 10um hcp (hexagonal closed packed) pores patterns

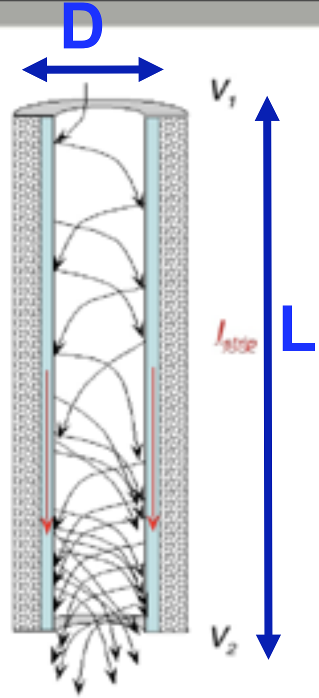
- Diameters of pores and pore-to-pore distance can be varied by drawing pattern

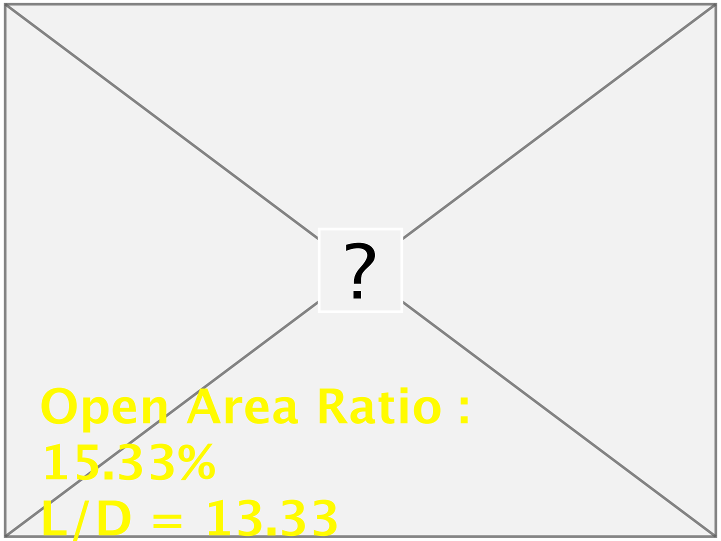


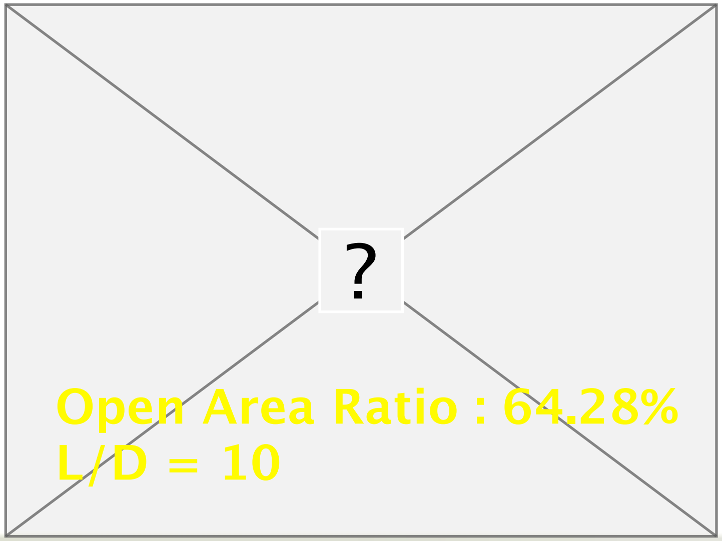


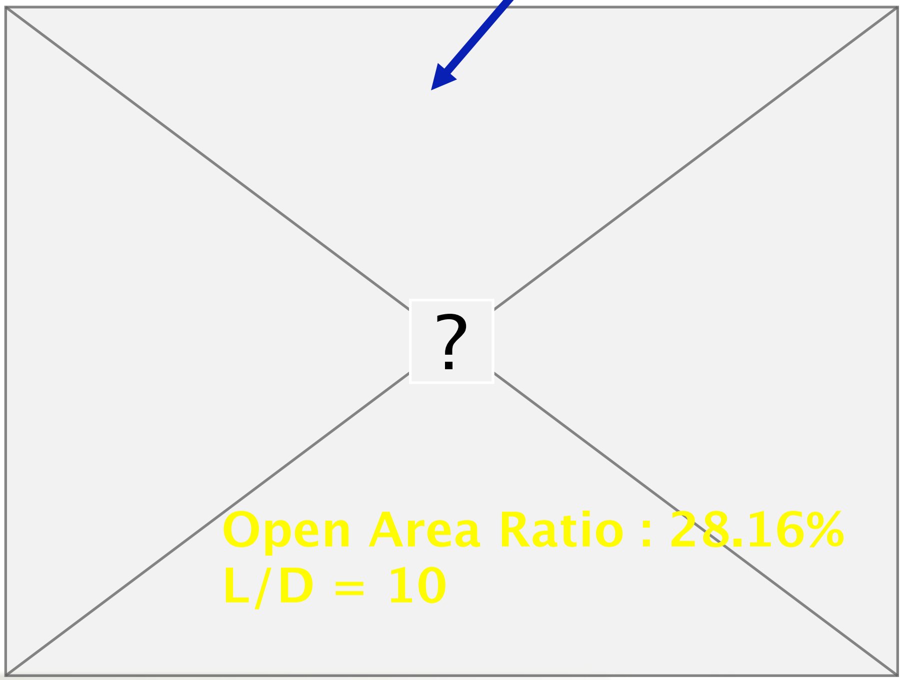
Optimize L/D to maximize gain

a. Electron multiplication is determined by channel aspect ratio Length to Diameter (L/D).
b. Maximize open area ratio

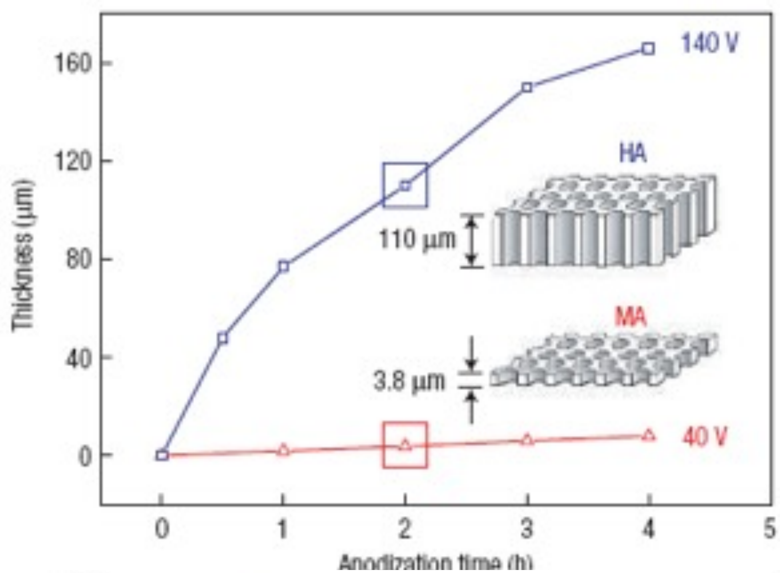


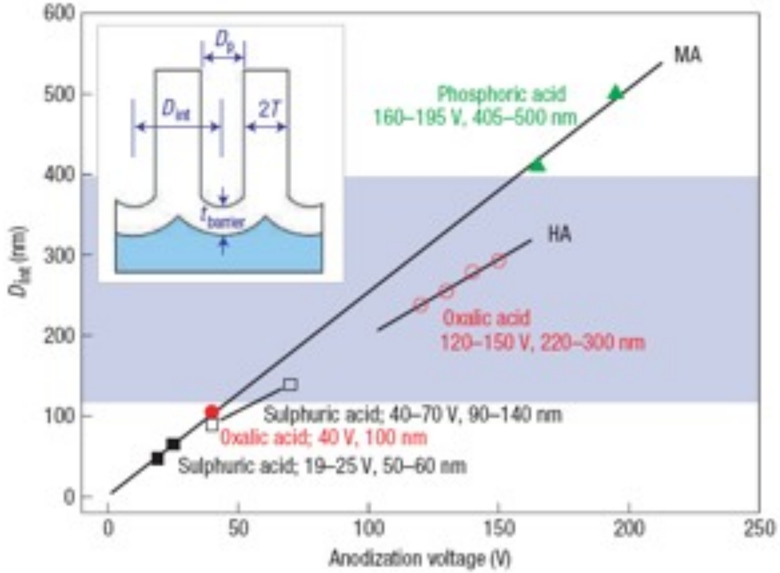


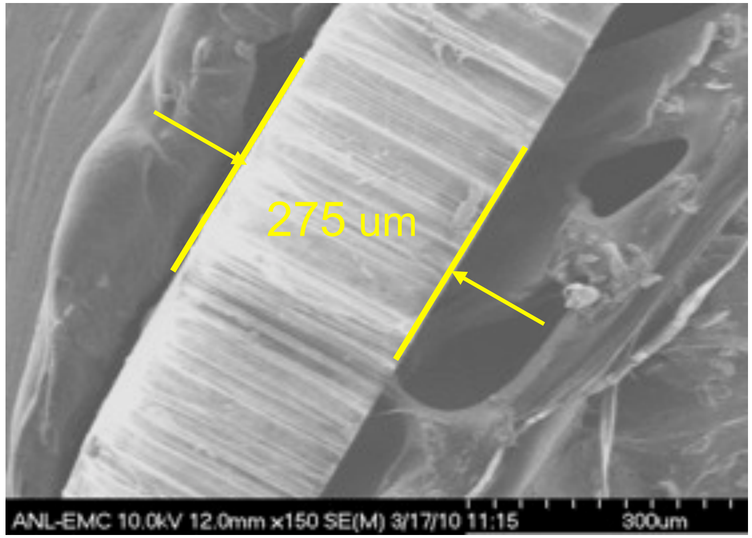


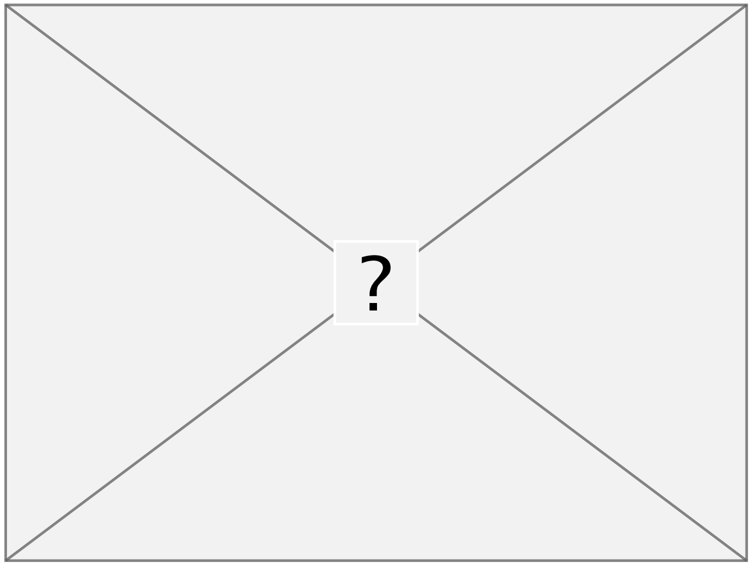


Thickness of AAO controlled through time and voltage









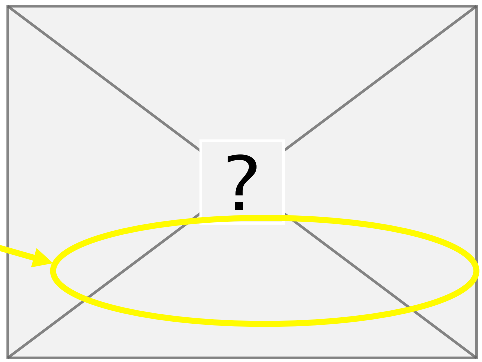
Lee et al. Nat Materials, vol 5, p741 (2006)

Aspect ratio

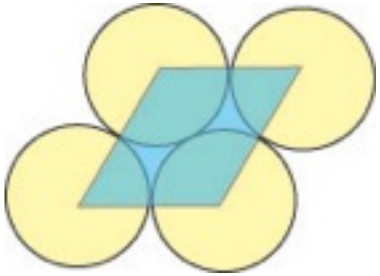
- Required AAO thickness (in μm) to meet the aspect ratio (L/D)
- White areas are straight forward

Aspect ratio L/D	Pore size D 0.5 μ	1 μ	2 μ	5 μ	10 μ	20 μ
40	20 um	40 um	80 um	200 um	400 um	800 um
60	30 um	60 um	120	300	600	1200
80	40 um	80 um	160 um	400 um	800 um	1600 um
100	50 um	100 um	200 um	500 um	1000 um	2000 um

Long anodization time in sulfuric acid leads to damage



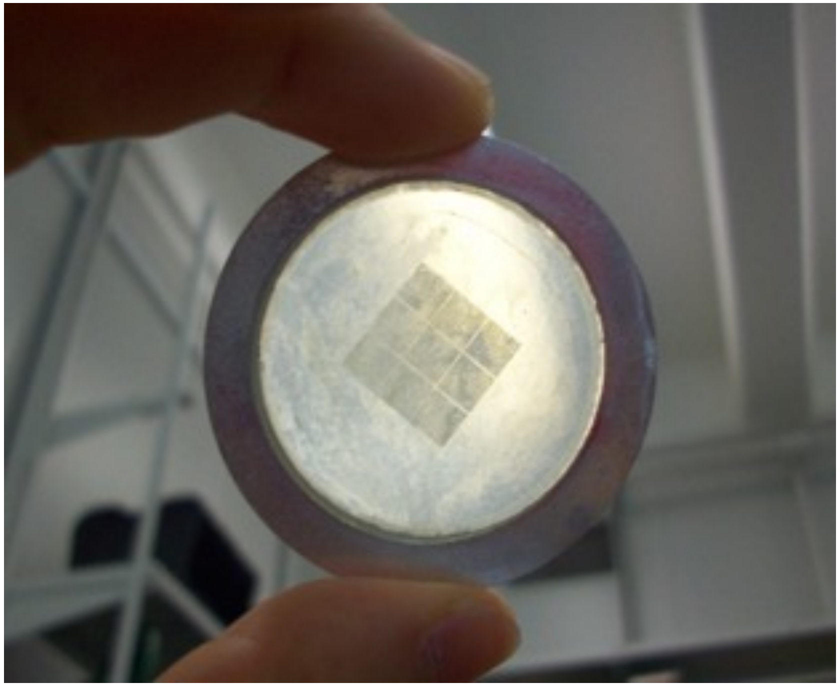
Open area

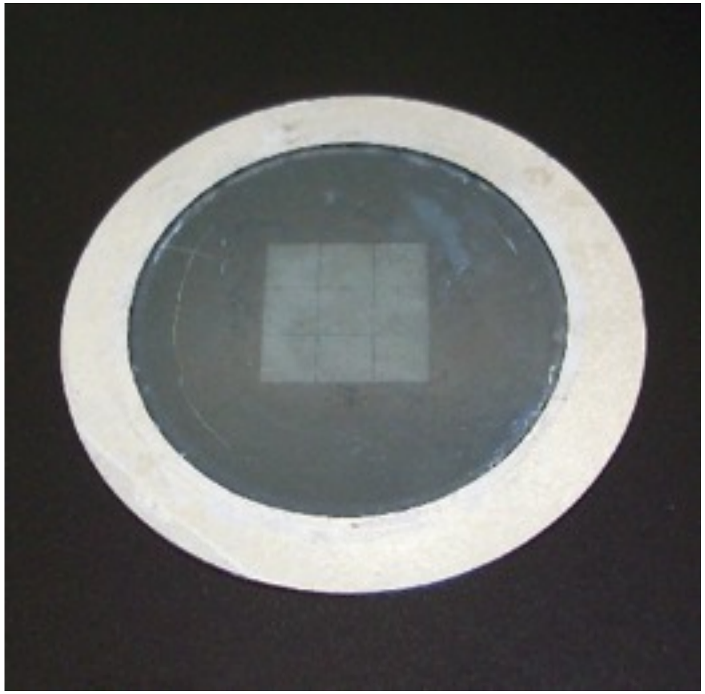


Pore size hcp structure a –pore	Pore-to-pore distance	Calculated open ratio	Accomplishment
a	2 a	22.7 %	Accomplished (3/2010)
a	1.5 a	40 %	Accomplished for small area test sample
a	1.25 a	58 %	Accomplished for small area test sample
a	1.10 a	78.7 %	Demonstrated (7/2010)
a	a	90.7%	Possible only with

- Open area up to 80% is feasible.
- 90% open area is only possible if funnel shaped entrance can be prepared.

Status of testable AAO based MCP at Argonne



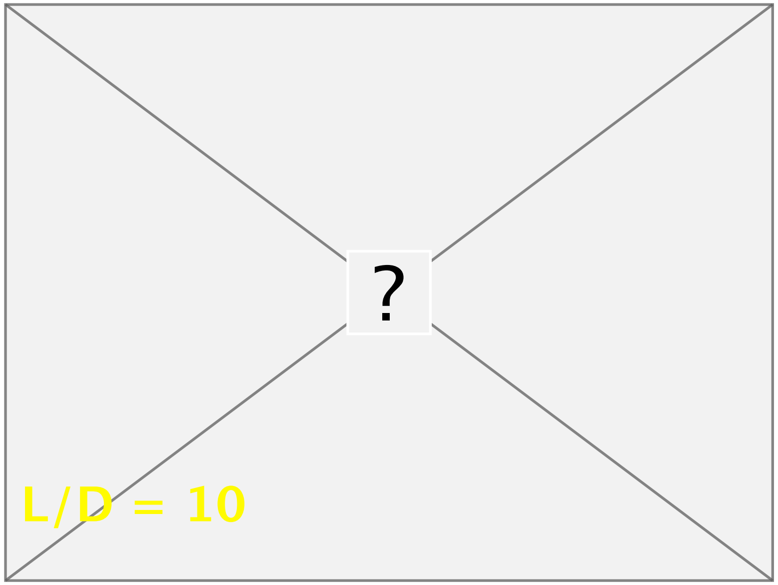


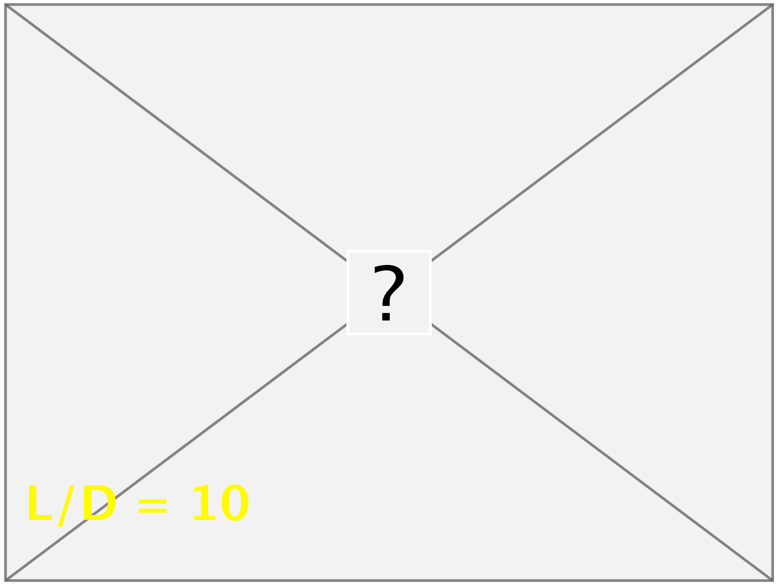
- 32.8 mm free standing AAO
- Pore size : 20 um
- Open area ratio : 22.66%
- L/D : 10

Optical image: Front 10X   Back 20X

SEM images - AAO with etched pores

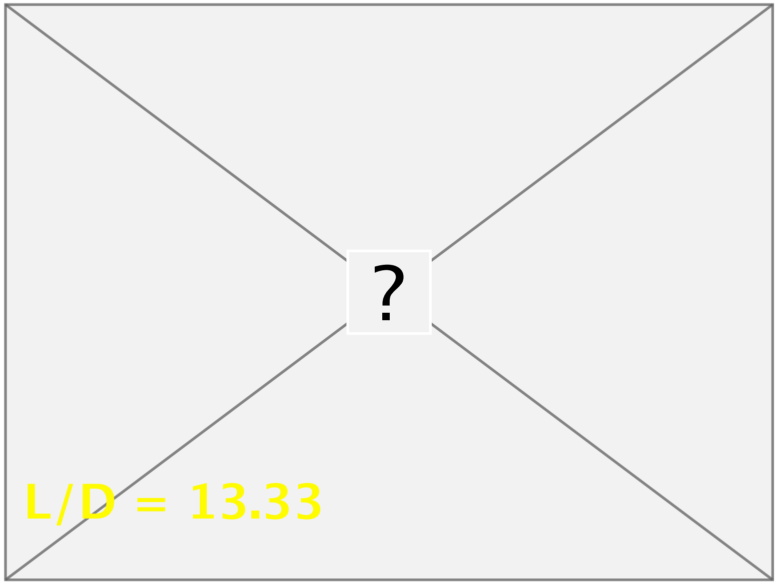
20 μm
front

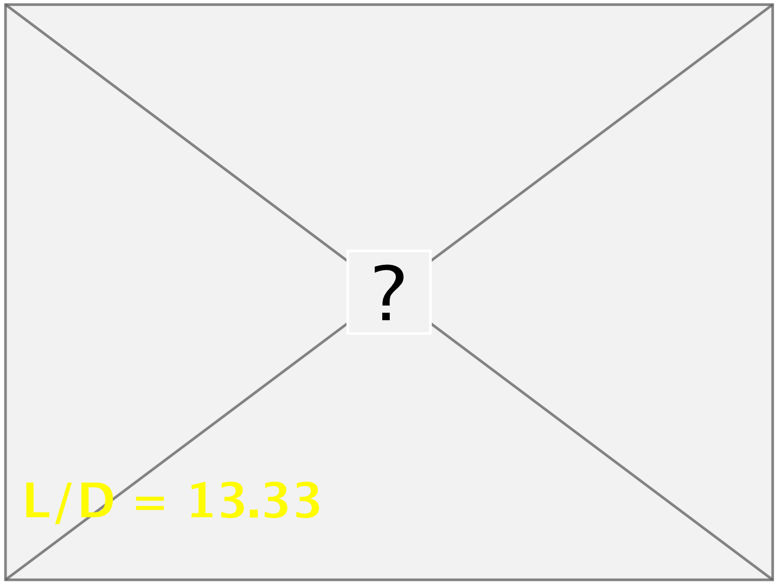




20 μm
back

15 μm
front





15 μm
back

Challenges in AAO etching

- 1. General difficulty

  Optical imaging is not sufficient to determine the degree of etching

  SEM imaging is required to follow the process
- 2. Uneven etching –

  The Al surface should be as smooth and even as possible

  Avoid AAO surface contamination (hydrophilic vs. hydrophobic areas)

  Stirring of the etching solution
- 3. Alumina nanowires hanging inside the patterned pores

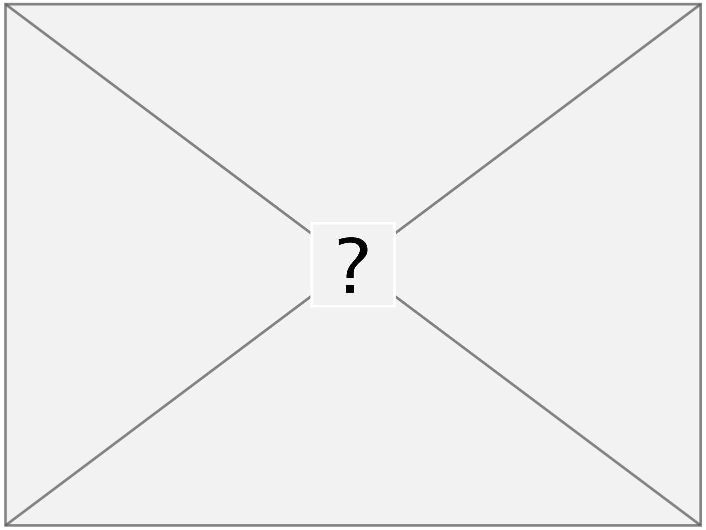
  Mild sonication helps to remove these nanowires
- 4. Slight over-etching creates the desired funnel-shaped entrance

  Timing is very critical

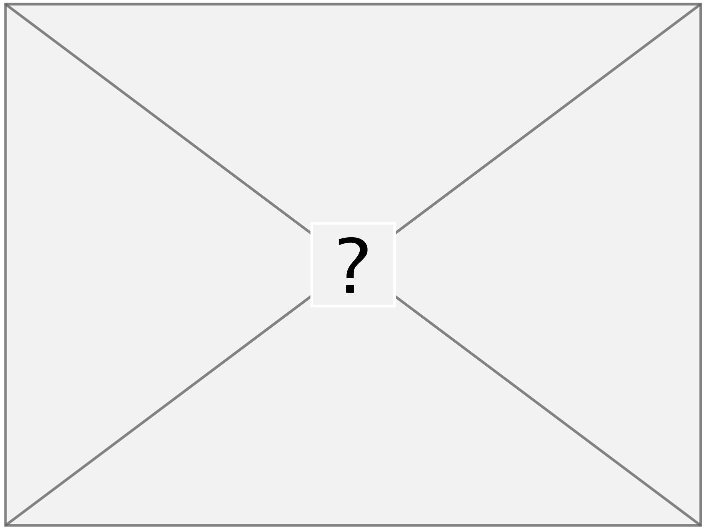
  Over-etching will destroy the membrane
- 5. Open area can be controlled through etching

  Timing is very critical

Effect of sonication - clean up pores

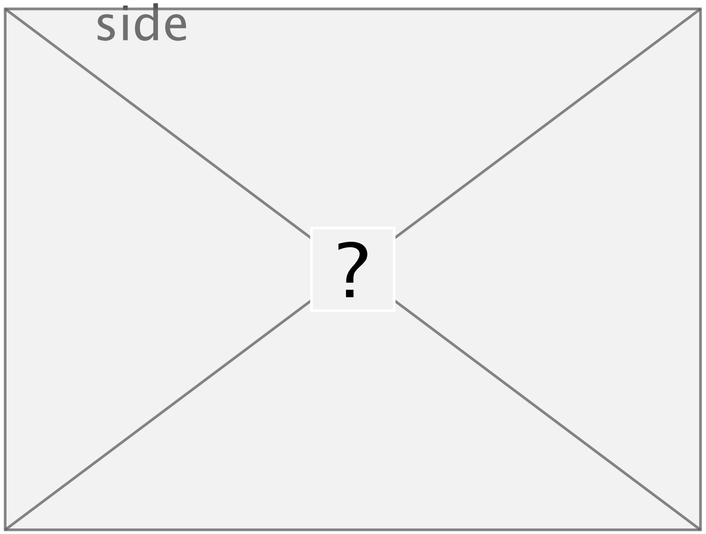


AAO after etching – back side

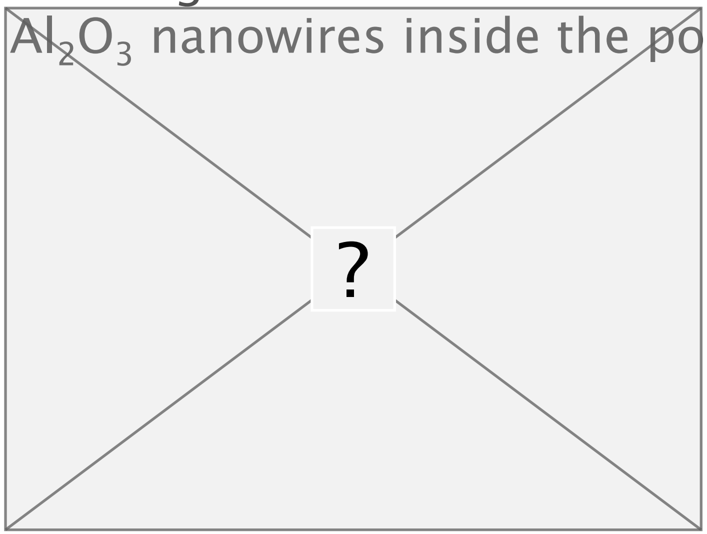


AAO after etching – front side, showing Al_2O_3 nanowires inside the pores

12 μ pores

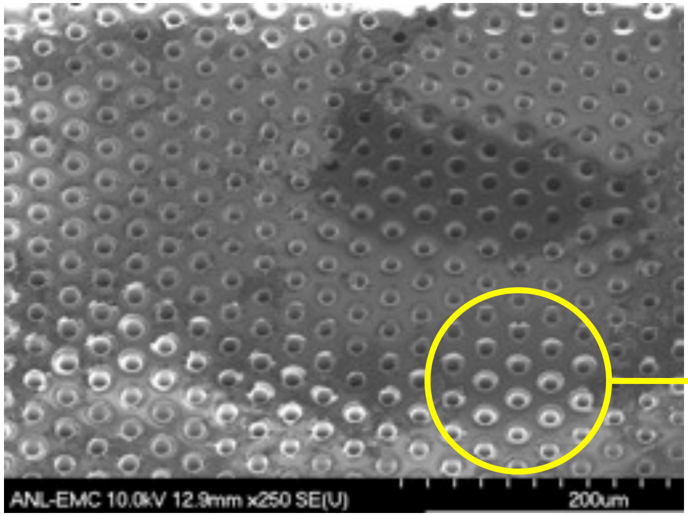


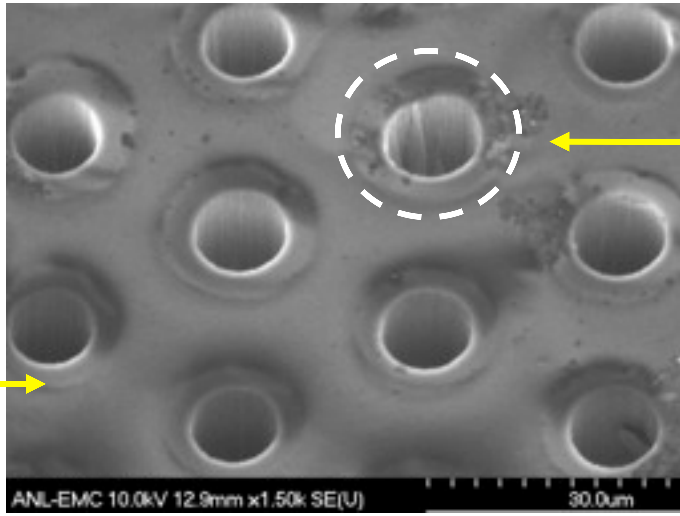
Back side – after sonication



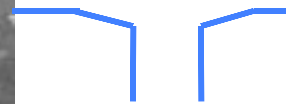
Back side – after sonication

Funnel-shaped entrances through etching

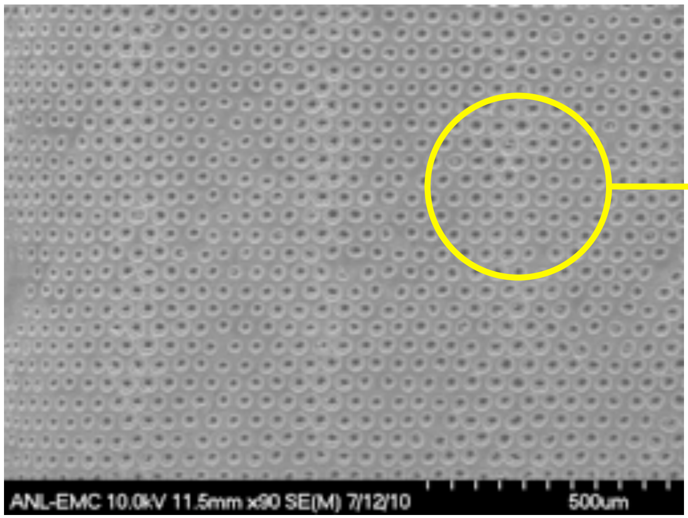


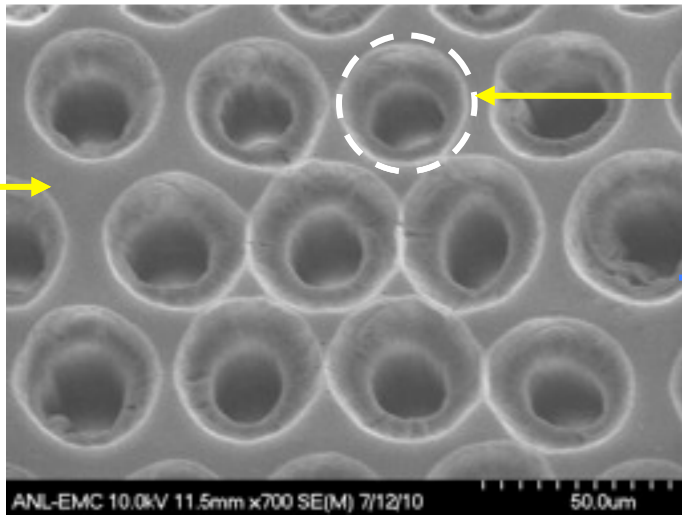


Shallow
funnel angl

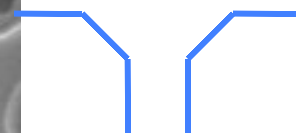


AAO membrane with 10 μm pores – slightly over-etched



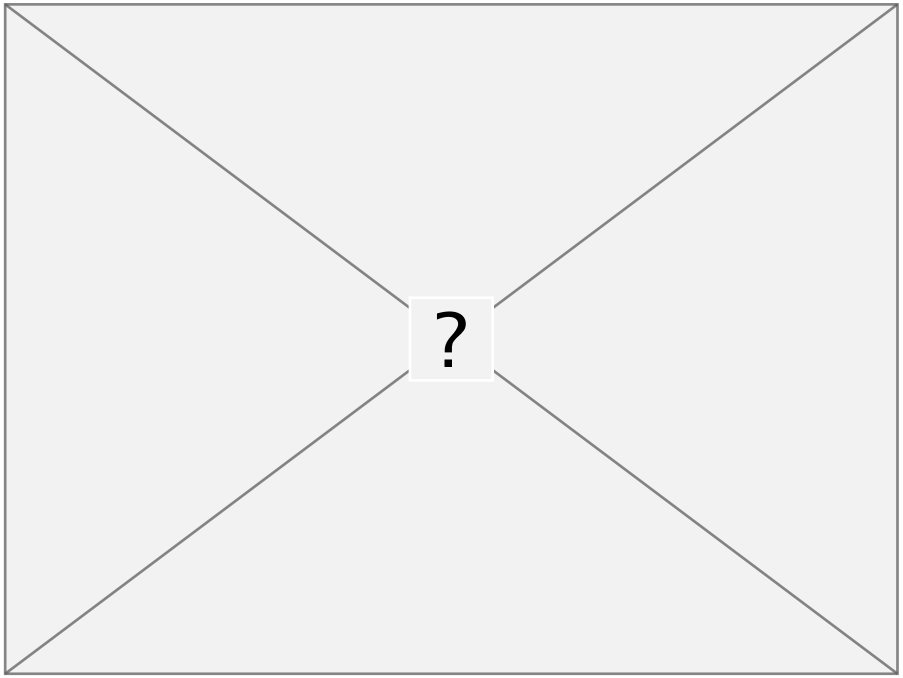


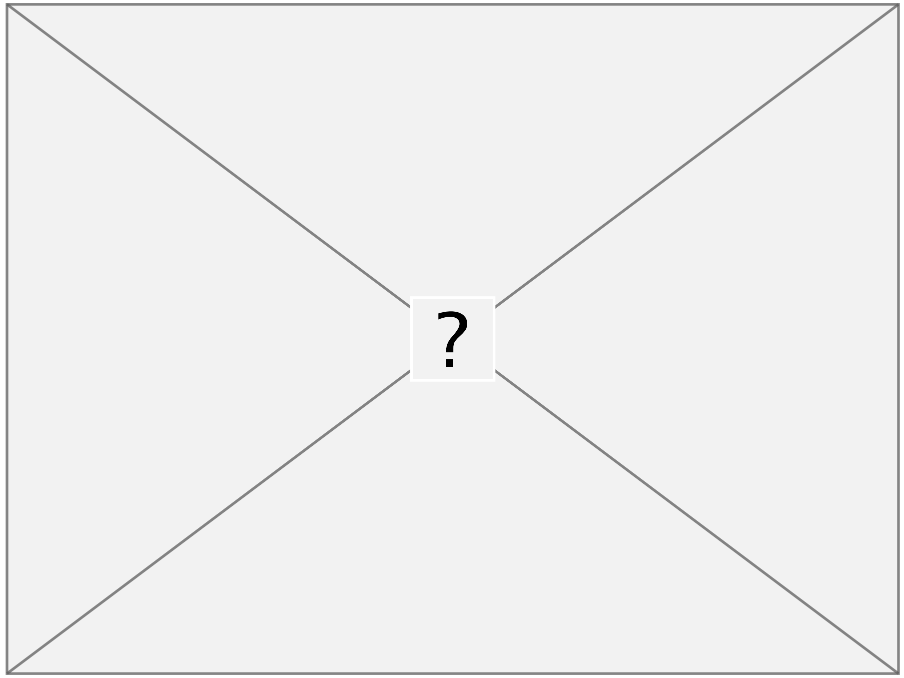
Much deepe
funnel angle



AAO membrane with 15 μm pores – more over-etched

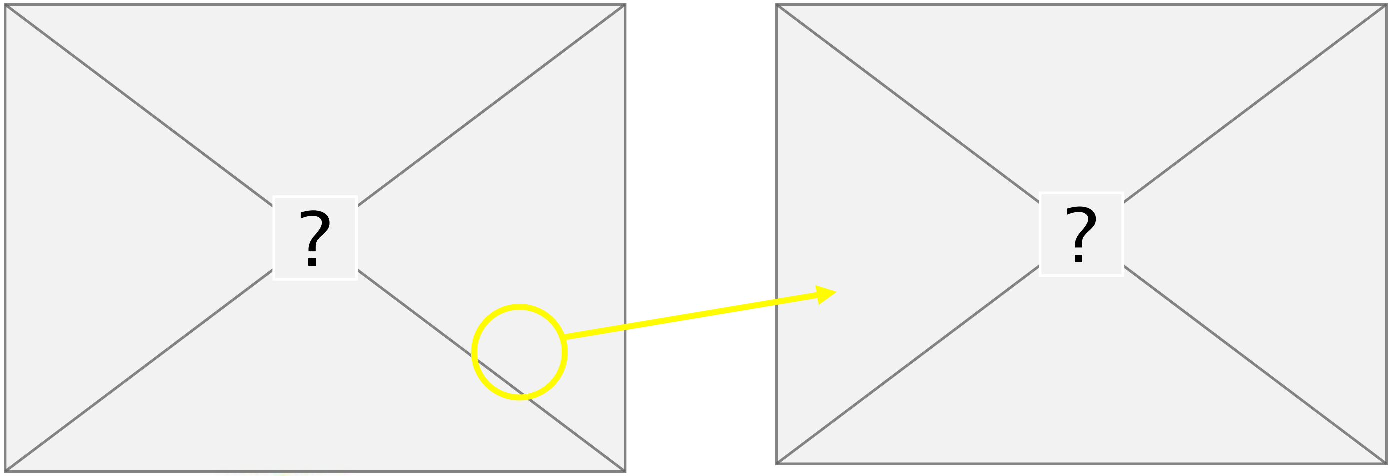
Open area ~78% is demonstrated

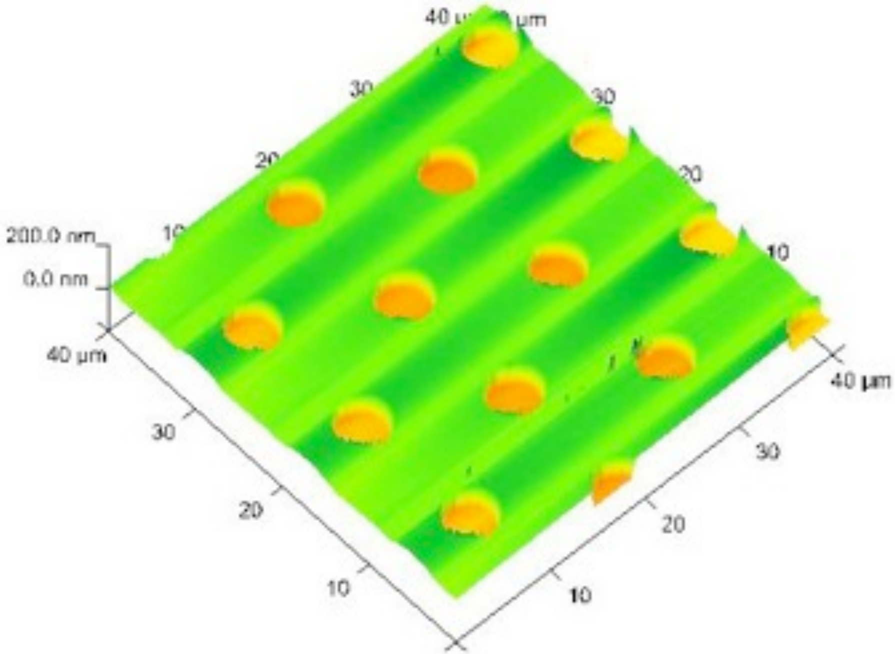


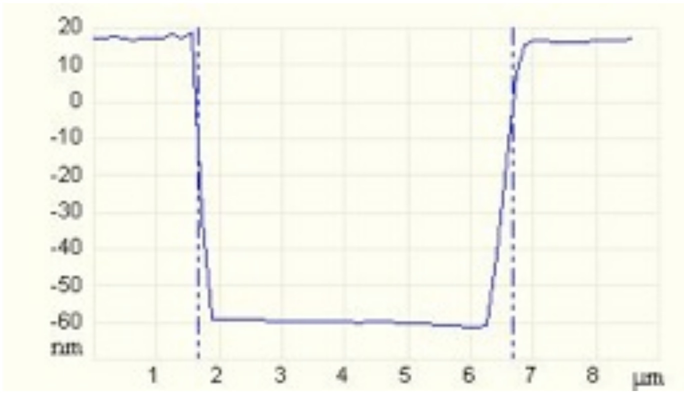


AAO membrane with 18 μm pores and 78% open area

5 μm pore photomask (15×15 mm^2) is prepared







Photomask with 5.0 μm pores is ready

AFM image (left) and depth profile (right)

Summary and Future direction

- AAO based MCPs with 20- to 10-μm micro-machined pores have been developed.
- The following challenges have been overcome:

  a) Loose alumina nanowires in the micro-machined pores

  – Removal through sonication

  b) Controllable funnel-shaped pore entrance – demonstrated

  c) Open area up to 78% – demonstrated

- 5 μm pore photomask is ready for photo-lithography
- Working with the ALD group for secondary electron emission coating, avoid sample bending, ..etc.
- Working with the characterization and laser testing groups on ALD/AAO/MCPs
- Scale up to 8x8" samples

Year 1 milestone:
(a) Achieve straight pores in AAO with diameter 0.7 microns (no-funnel option), $40 < L/D < 100$, and
open-area ratio 60 %;
(b) Demonstrate the feasibility of making AAO funnels suitable for photo-cathode deposition;
(c) Produce blanks of 32.8mm AAO plate for tests and MCP development.
(d) Evaluate the process economics.

Detector applications suitable for AAO based MCPs?

Pro / AAO strength

- Small pores (30–350 nm intrinsic pores) are readily available that are not feasible with glass fibers
- Larger pores (500 nm – 40 μm) can be fabricated
- Special requirement such as funnel-shaped entrance can be fabricated
- Small pores may provide faster timing and spatial resolution

Con

- Chemical etching requires extensive optimization
- Porous alumina is not as strong as glass
- Membrane thicker than 500 μm is hard to make